OPEN FOR INNOVATION:
The role of openness in explaining innovation performance among UK manufacturing firms

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ABSTRACT

A central part of the innovation process is the way firms go about organizing their search for new ideas that have commercial potential. New models of innovation have suggested that many innovative firms have changed the way they search for new ideas, adopting open search strategies that involve the use of a wide range of external actors and sources to help them achieve and sustain innovation. Using a large-scale sample of industrial firms drawn from the UK innovation survey, this paper links search strategy to innovative performance, finding that searching widely and deeply is curvilinearly (taking an inverted U-shape) related to performance.

Keywords: openness, search, innovation, innovative performance

INTRODUCTION

This paper explores the relationship between the openness of firms' external search strategies and their innovative performance. Chesbrough (2003b) suggests that many innovative firms have shifted to an "open innovation" model, using a wide range of external actors and sources to help them achieve and sustain innovation. This perspective builds on the common observation that firms rarely innovate alone and that the innovation process is interactive, involving relationships among producers, users and many other different institutions (von Hippel, 1988; Lundvall, 1992). A central part of the innovation process is the way firms go about conducting their search for new ideas that have commercial potential. Thus, search processes inside the firm can be seen an investment in the ability to create, use and re-combine new and existing knowledge. A variety of empirical studies have indicated that the character of a firm's search strategy can significantly influence its innovative performance (Ahuja, 2000; Katila, 2002; Katila & Ahuja, 2002). Accordingly, a search strategy itself is often seen a dynamic capability that allows firms to gain and sustain competitive advantage (Eisenhardt & Martin, 2000).

In this paper, we examine the influence of external search strategies in shaping innovative performance. In doing so, we develop the concepts of *breadth* and *depth* as two components of the openness of individual firms' external search strategies. We link the breadth and depth of external search to innovative performance, exploring how differences in search strategies among firms influence their ability to achieve different levels of novelty in their innovative performance. We find that search matters for innovation performance. Firms who are more open – those who search widely and deeply – tend to be more innovative. However, we find that too much openness can have a negative impact on performance, indicating that there is a point where search becomes counterproductive. We explore the implications of this finding for theories of managerial attention and for innovative performance.

The research is based on a statistical analysis of the UK innovation survey. The survey explores the innovation process inside firms and it contains a sample of 2707 firms drawn from manufacturing industries. The method of analysis is a double-truncated Tobit model where the dependent variable is innovative performance which

is explained by firm's external search strategies and a number of control variables, such as R&D and size.

The paper is organized into five sections. Section 1 explores the literature and examines the influence of external search on innovative performance, describing the hypotheses that drive the analysis. Section 2 outlines the database and section 3 describes the model. Section 4 reports the results and section 5 is the discussion and conclusions.

THEORETICAL BACKGROUND

The role of networks, communities and linkages has come to the fore in investigations of innovative performance. The early Schumpeterian model of the lone entrepreneur bringing innovations to markets has been superseded by a rich picture of different actors working together in iterative processes of trail and error to bring about the successful commercial exploitation of a new idea (Schumpeter, 1942/87; von Hippel, 1988; Freeman & Soete, 1997; Tidd, Bessant, & Pavitt, 2000). These new models of innovation have highlighted the interactive character of the innovation process, suggesting that innovators rely heavily on their interaction with lead users, between different functional departments within the firm and with a range of institutions inside the innovation system (von Hippel, 1988; Lundvall, 1992; Brown & Eisenhardt, 1995; Szulanski, 1996). In this respect, innovators rarely innovate alone. They tend to band together in teams and coalitions based on "swift trust", nested in communities of practice and embedded in a dense network of interactions (Scott & Brown, 1999; Brown & Duguid, 2000).

A recent example of the emerging consensus about the interactive, distributed and open nature of innovation can be seen in Chesbrough's "open innovation" model (2003b; 2003a). This model suggests that the advantages that firm's gain from internal R&D expenditure have declined. Accordingly, many innovative firms now spend little on R&D and yet they are able to successfully innovate by drawing in knowledge and expertise from wide range of external sources. The decline in the strategic advantage of internal R&D is related to the increased mobility of knowledge workers, making it difficult for firms to appropriate and control their R&D investments. Chesbrough argues that open innovators commercialize external ideas by

deploying outside (as well as in-house) pathways to the market (Chesbrough, 2003a). This process redefines the boundary between the firm and its surrounding environment, making the firm more porous and embedding it in loosely-coupled networks of different actors, collectively and individually working toward commercializing new knowledge.

At the center of the open innovation model and other similar conceptualizations of innovation is how firms' use ideas and knowledge of external actors in their innovation processes. Chesbrough (2003a) suggests that firms that are "too focused internally" are "prone to miss a number of opportunities because many will fall outside the organization's current business or will need to be combined with external technologies to unlock their potential". An example of this open innovation model can be seen in Proctor and Gamble's (P&G) approach to R&D. In order to ensure greater exploitation of external ideas and actors, P&G shifted its R&D strategy toward to "connect and develop" rather than focusing on internal R&D. P&G appears to be opening itself up to a wide range of external sources of develop innovative ideas, explicitly drawing in the ideas of others. The "connect and develop" model is based on the idea that external sources of ideas may often be more valuable than internal ones. Accordingly, open innovators are those that integrate these external sources into their innovation processes and competitive strategy (Chesbrough, 2003a).

The focus on openness and interaction in studies of innovation reflects a wider trend in studies of firm behavior that suggest the network of relationships between the firm and its external environment can play important role in shaping performance. For instance, Shan, Waker and Kogut (1994) find an association between cooperation and innovative output in biotechnology start-up firms. Ajuha (2000) finds that indirect and direct ties influence the ability of a firm to innovate, but that the effectiveness of indirect ties is moderated by the number of a firm's direct ties. Rosenkopf and Nerket (2001) explore the role of boundary spanning searches for both organizational and technological boundaries and find that search processes that do not span over organizational boundaries generate lower effects on subsequent technological evolution, indicating the impact of explorative search is greatest when the search spans both organizational and technological boundaries. Powell, Koput and Smith-Doerr (1996) investigate inter-organizational collaboration in biotechnology and

assesses the contribution of collaboration to learning and performance, suggesting that firms embedded in benefit-rich networks are likely to have greater innovative performance. In sum, all these studies point to the importance of open behavior by firms in their search for innovative opportunities and they suggest that performance differences between organizations can be ascribed to this behavior.

Eisenhardt and Martin (2000) also highlighted the role of search processes and interaction in the development of dynamic capabilities, pointing to the importance of manipulation of knowledge resources in dynamic and unpredictable environments. They suggest that knowledge creation and alliance forming routines provide a mechanism to bring new resources into the firm from external sources. In dynamic environments, firms often rely on simple, experimental and iterative search processes to innovate. They argue that differences between firms in how they search can be a source of resource heterogeneity and lead to variations in innovative performance (Eisenhardt & Martin, 2000).

Investigating search has also become a key element in efforts to explain innovative performance. Using patent evidence from the robotics and chemical sectors, Katila (2002) and Katila and Ahuja (2002) investigate the link between search strategy and innovative performance. These studies demonstrate that the age of knowledge and the depth and scope of search processes can influence the potential for innovation. Together these studies shift attention toward the role of search strategies in explaining innovative performance and suggest that the conventional explanatory variables of innovation performance, such as size and R&D expenditure, need to be complemented by investigation into how differences in search strategy give rise to performance heterogeneity.

Our approach builds on and extends previous literature in three ways. First, whereas Katila (2002) and Katila and Ahuja (2002) focus on search inside the firm and across a technological trajectory (as reflected in patents), we focus on firm's external innovative search efforts. We seek to examine how different strategies for using external sources of knowledge for innovation influence innovative performance. Our approach focuses on the search channels, such as suppliers, users and universities, that firm's use in their search for innovative opportunities. The concept of search channels

shifts attention toward the pathways of exchange between a firm and its environment. It provides a mechanism to explore relationship between openness and innovative performance.

Second, the preceding studies of search and innovation say relatively little about the way firms draw external ideas into their innovation processes. These studies are largely based on analyses of patent data and patents can reflect both inventive activities and the appropriability strategy of the firm. Not all patents are commercialized and they are widely acknowledged to be a partial indicator of the innovation process (Levin, Klevorick, Nelson, & Winter, 1987; Klevorick, Levin, Nelson, & Winter, 1995). In contrast, our approach builds on methods employed in the Yale survey. It is based on questionnaire survey of managers in manufacturing firms, asking them directly about what sources of knowledge they rely upon in their innovation activities. This approach allows us to examine the nature of external search strategy, highlighting the range of choices firms make how best to exploit external sources of knowledge.

Third, by using the UK innovation survey, it is possible to investigate the impact of search on different types of innovation. The UK innovation survey provides estimates of the degree of novelty of innovation achieved by the firm and therefore it is possible to see if the search affects different types of innovative performance.

HYPOTHESES

The underlying proposition for the research is that openness is associated with innovative performance, that is, those firms who draw widely and deeply from external sources of innovation will exhibit higher levels of innovative performance. In order to examine this question, we develop two concepts. The first concept refers to external search breadth, which is defined as the number of external sources or search channels that firms rely upon in their innovative activities. The second concept refers to external search depth and it refers to the extent to which firms draw deeply from the different external sources or search channels. Together the two variables represent the openness of firms' external search processes.

External search breadth

A central component in the movement toward open or interactive innovation models is a change in the way firms go about searching for new ideas and technologies for innovation. Product search can be defined as an "[o]rganisation's problem-solving activities that involve the creation and recombination of technological ideas" (Katila & Ahuja, 2002). The product development process is itself a form of problem solving and associated search processes involve not only investments in the people and technologies of search, but also the building and sustaining links with users, suppliers and wide range of different institutions inside the innovation system (von Hippel, 1988). Search is an active process of both investment and interaction. As Koput (1997) suggests, however, innovative search is often coupled to an implementation process. Accordingly, search needs to be understood in the context of a range of investments in the activities necessary to bring about the innovation. Moreover, the "level of innovative search must be actively linked to the organization's capacity for processing and implementing the outcomes of the activity" (Koput, 1997). In other words, firms require the capability to absorb new ideas from external sources and then integrate them their internal processes to achieve an innovation (Cohen & Levinthal, 1989; Cohen & Levinthal, 1990).

Two previous studies are especially pertinent to our approach. First, Katila (2002) explores how the age of technological knowledge from within and outside an industry shapes product search and innovative performance in the robotics industry. This study finds that differences in innovative performance are based on differences in how firms deploy knowledge from different industries and over time. Second, Katila and Ahuja (2002) examine how search depth, i.e. how the firm reuses its existing knowledge, and search scope, that is how widely the firm explores new knowledge, influence innovative performance. They suggest that these concepts provide an extension of March's (1991) distinction between exploration and exploitation, contrasting the differences between local and distant search processes. In their study, search depth is measured by the "number of times a firm repeatedly used the citations in the patents it applied for" and search scope is measured as "share of citations found in a focal year's citations that could not be found in the pervious five years' list of patents and citations by the firm" (Katila & Ahuja, 2002). They find that a firm's innovative

performance is in part a function of its search behavior and that there is a curvilinear relationship – taking an inverted U-shape – between depth and scope on the one hand and innovative performance on the other, indicating that some firms have a tendency to "over-search" (Katila & Ahuja, 2002).

Extending on Ahuja and Katilia, we focus on external search breadth and innovative performance. External search breath is defined as the number of different search channels that a firm draws upon its innovative activities. In theory, drawing from a wide number of sources of knowledge should increase the potential for firms to innovate. It should be noted that our concept of external search breadth differs from Kalita and Ahuja's concept of "search scope" which they define as the use of new knowledge in patents.

We hypothesize that external search breadth is associated with innovative performance. Yet, we also argue that firms may over-search and that this will have negative consequences for their innovation performance. Some firms suffer from the problems highlighted by Koput (1997), extending themselves too far in efforts to capture external ideas in their innovation processes. In this context, Koput provides three reasons why over-searching may have a negative influence on performance. First, there may be too many ideas for the firm to manage and choose between. Second, since there are so many ideas, few of these ideas are taken seriously or given the required level of attention or effort to bring into implementation. Third, many innovative ideas may come at the wrong time and in the wrong place to be fully exploited (Koput, 1997).

The idea of over-search can be linked to attention-based theories of the firm and to studies of managerial attention (Ocasio, 1997). The attention-based theory of the firm suggests that managerial attention is the most precious resource inside the organization and the decision to allocate attention to particular activities is a key factor in explaining why some firms are able to both adapt to changes in their external environment and to introduce new products and processes. Central to this approach is to highlight the pool of attention inside the firm and how attention is allocated. It suggests that poor allocation of managerial attention can lead to firms engaging in too many (or too little) external and internal communication channels (Ocasio, 1997).

Both Koput's model of innovative search and Ocasio's attention-based theory of the firm suggest that there is a point at which external search breadth becomes disadvantageous. In sum, the hypothesis can be stated as:

H1. External search breadth is curvilinearly (taking an inverted U-shape) related to innovative performance

External search depth

Search for new ideas is not just about accessing a wide number of sources; it also involves developing links with these sources. Many firms will develop links with key sources of ideas that they need to draw upon to innovation. These may include lead users, suppliers or universities. For each of these links, firms need to sustain a pattern of interaction over time, building up shared understanding and common ways of working together. Assessing the depth of the external links of firms provides a mechanism to understand the way firms draw from external sources and how these sources are integrated into their internal innovative efforts.

Katila and Ahuja (2002) found that search depth, measured as the extent which firm used past knowledge, to be a significant factor in shaping innovative performance. Search depth allowed firms to reuse their existing knowledge, allowing them to build on experience and enhance predictability. However, Ahuja and Kalita's concept of search depth refers to the reuse of knowledge as measured by the number of citations to past patents of the firm, and therefore it says little about external search. In order to explore the importance of search depth for external sources, we extend Ahuja and Katila's concept to search depth to focus on external search depth.

Our concept of external search depth is very different and is defined as the extent to which firms draw deeply from different search channels or sources of innovative ideas. It reflects the ties between the firm and a particular source of innovation, indicating a reliance on this source for internal innovative processes. We expect firms that draw deeply from external sources to be more innovative, because they are been able to build and sustain virtuous exchanges with external actors. However, we expect to find that some firms can become too deeply reliant on external sources for

innovation (Katila & Ahuja, 2002). Maintaining deep links with external resources requires resources and attention. As suggested by Koput and Ocasio, building too many deep linkages can spread a firm's attention, diluting its ability to exploit fully the ideas it gains from one source. Therefore, we expect to find that if a firm relies of too many deep relationships with external sources, it will exhibit lower innovative performance. The hypothesis can be stated as:

H2. External search depth is curvilinearly (taking an inverted U-shape) related to innovative performance

Novelty of innovation

It is common in studies of innovation to explore the differences in the innovation process for innovations exhibiting different degrees of novelty (Freeman & Soete, 1997). A variety of empirical studies have shown that the level of novelty of an innovation strongly influences the factors that shape innovative performance (Garcia & Calantone, 2002). Taxonomies of novelty of innovation extend from radical and truly revolutionary, such as the microchip, to the incremental, such as changing packaging on existing products (Henderson & Clark, 1990; Freeman & Soete, 1997; Tidd et al., 2000). Novel innovations seem to offer the greatest opportunity for performance differences (Marsili & Salter, 2003). Tushman and Anderson classified radical innovation in terms of "competence-enhancing" or "competence-destroying", reflecting the different ways novel innovations alter patterns of industrial competition among firms working within the industry (Tushman & Anderson, 1986; Anderson & Tushman, 1990). To achieve novel innovation, firms often need to make a considerable investment in R&D and the chances of success are lower as the rewards are great. As Schumpeter stated, novel innovation offers "the carrot of spectacular reward or the stick of destitution" (1942/87). On the contrary, incremental innovation is more common. It requires less effort and its performance implications appear to be more modest (Marsili & Salter, 2003).

To our knowledge little work has been carried out on the relationship between the degree of novelty of the innovation and the breadth and depth of firms' innovative search strategies, let alone firms' external innovative search strategies. However, since radical innovation may involve a higher degree of discontinuity in the sources of

innovation, we expect that the use of a few new sources of innovation – used intensively – to be important in the case of more radical innovations. Given that radical innovations are by definition genuinely novel, they are less likely to be embedded (Granovetter, 1985) in a broad network of sources of innovation, since it takes time to develop such a broad network of sources. However, for more incremental innovations, after when a dominant design has emerged (Abernathy & Utterback, 1975), we expect that a broad variety of sources may be important. After a dominant design has emerged it may be time for "fine-tuning" the product by means of incremental innovations inspired by many different sources of innovation, each making an incremental impact. In other words, radical innovators are likely to draw more deeply from external sources of innovation than firms that are not radical innovators, while incremental innovators are likely to draw more broadly (but less intensively) than non-innovators. These arguments can be stated in the following two hypotheses:

H3. The more radical the innovation, the less effective external search breadth will be in influencing innovative performance.

H4. The more radical the innovation, the more effective external search depth will be in influencing innovative performance.

Role of lead users

Many studies of innovation have found that key source for innovations are lead users. Since the SAPPHO project in the early 1970s, a number of studies have shown that users are often the key source of innovation in a variety of sectors (Rothwell, Freeman, Jervis, Robertson, & Townsend, 1974; von Hippel, 1988). For example, Riggs and von Hippel (1996) found that 44% of a sample of innovations in scientific instrumentation could be ascribed to the work of lead users. Urban and von Hippel (1998) suggest that lead users are important for innovation, because they are usually ahead of the market, facing problems before others and in position to benefit greatly from any new solutions. Lead users draw innovations from manufacturers and/or develop or significantly shape the innovations themselves. Interacting with lead users provides an opportunity for firms to gain deep insights to develop new solutions to old problems (von Hippel, 1998). Much of the information held by users is sticky and

difficult to transfer and therefore firms often have to expend considerable resources and time to draw out users' insights. However, the benefits from such efforts can by high and many innovative firms are characterized by their ability to transfer this sticky information into their design and production process through a number of tools, such as "user toolkits" (von Hippel & Katz, 2002).

Given the widespread importance placed on the role of lead users in the innovation process, we would expect to find that those firms that draw deeply from users in their search for innovation will be more innovative than those who fail to draw deeply from users. This can be stated as the hypothesis:

> *H5. Drawing deeply from lead users in innovative search increases the probability of the firm to achieve innovative performance.*

DATA AND METHODS

Sample

The data for the analysis is drawn from the UK innovation survey. The survey was implemented in 2001 and is based on the core Eurostat Community Innovation Survey (CIS) of innovation (Stockdale, 2002; DTI, 2003a). The method and types of questions used in innovation surveys are described in the Organization for Economic Co-operation and Development's (OECD) Olso Manual (OECD, 1997). CIS data are increasingly being as used as a key data source in the study of innovation at the firm level in Europe, Canada and Australia (for a recent prominent contribution using CIS data, see Mairesse & Mohnen, 2002). Within the Europe, CIS surveys are normally conducted every five years. CIS surveys of innovation often described as "subject-oriented" because they ask individual firms directly whether they were able to produce an innovation. They are widely piloted and tested before implementation and, since it was first use in the early 1990s, the questionnaire has been continuously revised. The CIS questionnaire itself draws from previous generations of research on innovation, including the Yale survey and the SPRU innovation database. It provides an opportunity to investigate patterns of innovation across a large number of industrial firms. It also enables researchers to explore the relationship between indicators of

performance and different strategies for innovating. Although imperfect, CIS data does provide a useful complement to the traditional measures of innovation, such as patent statistics (Kaiser, 2002; Mairesse & Mohnen, 2002).

The CIS questionnaire asks firms indicate whether the firm has been able to achieve a product innovation. Product innovation is defined as:

> goods and services introduced to the market which are either new or significantly improved with respect to fundamental characteristics. The innovations should be based on the results of new technological developments, new combinations of existing technology or utilization of other knowledge by your firm (DTI, 2003b).

Firms are then asked to state what share of their sales can be ascribed to different types of innovations, such as innovations new for the world. Alongside these performance questions, there are number of questions about the sources of knowledge for innovation, the effects of innovation, intellectual property strategies and expenditures on R&D and other innovative activities.

The UK innovation survey is 12 pages long and includes page of definitions. The sample of respondents was created by Office of National Statistics (ONS). It was sent to the firm's official representative for filling information on the firm's activities, such as surveys for calculating the UK Gross Domestic Product and R&D expenditures. On the survey, respondents were instructed to forward the survey to the department of the firm best able to respond to the different questions. The implementation of the survey was administered by the ONS and to guide respondents a help service was provided (Stockdale, 2002).

All firms are asked to complete the questionnaire, regardless of whether or not they innovated during the period of the survey. In this respect, the UK innovation survey is slightly different from other European CIS surveys. In previous, European surveys only innovators were asked to complete all the questions of the survey. However, the UK innovation survey includes information about their strategies and activities of both innovators and non-innovators. There is a potential selection bias in the sample because questions about the innovation process, such as the sources of knowledge for innovation, may be more pertinent to those firms who have recently innovated. The

questionnaire was designed to encourage all firms to respond to questions about their innovative activities. Overall, response rates among non-innovators were similar to innovators for questions relating to their strategies for innovation and many non-innovators appeared to have active strategies for innovation. With future generations of the UK innovation survey, it will be possible to explore what strategies or activities at a point in time are associated with ability to achieve of the innovation at a later point in time. At present, however, the UK innovation survey dataset is cross-sectional.

The survey was sent to 13,315 business units in the UK in April 2001 and a supplementary sample of 6,287 was posted the survey in November 2001. It received a response rate of 41.7% (Stockdale, 2002). The second mail out was designed to top-up the number of regional responses to the survey. The responses were voluntary and respondents were promised confidentiality and that the survey would be used to shape government policy. The sample was stratified by twelve Standard Industrial Classification classes and includes all main sectors of the UK economy, excluding public bodies, retail, and hotels and restaurants. The sample was also stratified by region and by size to reflect the total demographic characteristics of the UK economy. The response rates for different sectors, regions and size were largely consistent with the overall response pattern (Stockdale, 2002).

Descriptive results

Using UK innovation survey, we explore the knowledge sources for innovation in the UK. Table 1 lists all 16 external sources listed in the UK innovation survey. Each firm is asked to indicate on a 0-1-2-3 scale the degree of use for each source. On the survey, the sources are grouped together under six different headings (internal, market, institutional, other and specialized). Table 1 presents the results for the entire range of sources for UK manufacturing firms. Overall, the results indicate most important source is suppliers of equipment, materials and components, followed closely by clients and customers (or users). Alongside customers and suppliers, a range of standards, such as health and safety standards, are among key sources of innovation. As might be expected (see von Hippel, 1988), the results indicate that UK firms' innovation activities are strongly determined by relations between themselves and their suppliers and customers.

[Table 1, just about here]

In Table 2, we examine the level of external search breadth and depth across industrial sectors. Overall, we find that firms cited seven external sources of knowledge for innovation. Chemicals, electrical and machinery industries exhibit the highest level of external search breath, indicating the industries with medium to high levels of scientific and technological activity search widely. In contrast, low technology sectors, such as paper and printing, have the lowest levels of external search breath.

External search depth is less common. On average, firms draw from deeply from only one source. Search depth was greatest in the machinery, chemicals and transport industries. Textiles and wood product industries had little external search depth. Overall, we found a high correlation between the means of industries across external search breadth and depth, suggesting that both concepts are general reflections on the openness of sectors to external sources.

[Table 2, just about here]

Measures

Dependent variable

We use three proxies aimed at reflecting various types of innovative performance by firms. First, we use a variable aimed at indicating the ability of the firm to produce radical innovations. This variable is measured as the fraction of the firm's turnover relating to products new to the world market (INNWORLD). In addition, we add two variables as proxies for incremental innovation. First, we include a variable expressing the fraction of the firm's turnover pertaining to products new to the firm (INNFIRM) and another variable expressing the fraction of the firm's turnover pertaining to products significantly improved (INNIMP). These two variables a mutually exclusive since they — together with unchanged or only marginally modified products — add up to 1.

Independent variables

Variables key to the analysis

As determinants of innovative performance, we introduce two new variables reflecting openness in terms of external search strategies of firms.[1] The first new variable is termed BREADTH and is constructed as a combination of the 16 sources of knowledge or information for innovation listed in Table 1 of this paper. As a starting point, each of the 16 sources are coded as a binary variable, 0 being no use and 1 being use of the given knowledge source. Subsequently, the 16 sources are simply added up so that each firm gets a 0 if no knowledge sources are used, while the firm gets the value of 16, if all knowledge sources are used. In other words, it is assumed that firms who use higher numbers of sources will be more "open", with respect to search breadth, than firms who do not. Although our variable is based on relatively simple construction, it has a high degree of internal validity (Cronbach's Alpha Coefficient = 0.93).

The second variable is named DEPTH and is constructed using the same 16 sources of knowledge as those used in constructing BREADTH. In this case each of the 16 sources are coded with 1 if the firm in question reports that they use the source to a high degree and 0 in the case of no, low or medium use of the given source. As in the case of BREADTH, the 16 sources are subsequently added up so that each firm gets a 0 if no knowledge sources are used to a high degree, while the firm gets the value of 16, if all knowledge sources are used to a high degree (Cronbach's Alpha Coefficient = 0.76). Again, it is assumed that firms who use higher numbers of sources will be more "open" with respect to search depth, than firms who do not.

Although the list of sources on the questionnaire is not fully comprehensive, it is extensive and not mutually exclusive. It reflects a wide range of sources of innovation, including suppliers, clients and competitors as well as general institutions operating inside the innovation system, such as regulations and standards. The sources listed in the survey overlap with the resources and institutions that are considered part

[1] However, a very similar variable to that of the variable measuring search breadth has been used by Laursen and Salter (2003) as a predictor of the propensity of firms to use knowledge developed at universities.

of the national innovation system (Lundvall, 1992; Nelson, 1993; Spencer, 2001). Like previous literature on search strategy, we assume that firms have a degree of choice in how "open" they wish their innovative search processes to be, both with respect to search breadth as well as to search depth. This assumption is consistent with the literature on innovation search and managerial strategy in that it ascribes an important role to managerial choice in shaping the outlook of the firm to its external environment. Although the introduction of any variable into a well-established area of research is always contentious, the introduction of two new variables to reflect the openness of innovative search does enable researchers to better explore the link between innovative search and innovative performance.

Our variable reflecting the use of lead users in the process of innovation is constructed based on the "clients or customers" source of knowledge for innovation listed in Table 1. Simply the variable takes the value of 1 of the firm indicates that they use clients or customers to a high degree as sources of information and knowledge for innovation activities, and 0 otherwise.

Control variables

We include a measure of R&D intensity (RDINT), measured as firm R&D expenditure divided by firm sales. The numerator is taken from the UK innovation survey, while the denominator firm turnover or sales is based on Office of National Statistics register data, supplied with the survey data. Moreover, we include firm size and whether or not the firm was a recent start-up. Firm size (expressed in logarithms) is measured by the number of employees (LOGEMP). Whether or not the firm was a start-up in the period 1998-2000 (STARTUP) is based on a question on the survey about date of establishment of the firm. In addition, we control for the size of the perceived product market (GEOMARKET). The variable measures whether the largest market of the firm is perceived to be local, regional, national or international. This variable takes the values from 1 to 4, with 1 corresponding to "local" and 4 corresponding to "international". Furthermore – and using a binary variable – we control for whether or not firms engaged in co-operation arrangements on innovation activities (COOP), a supplementary question on the survey. Finally, we include 13 industry controls to account for different propensities to innovate across industries.

Statistical method and results

The dependent variable in the regression model is (double) censored, since the variable is the percentage of innovative sales and therefore by definition ranges between 0 and 100, a Tobit analysis is applied (see Greene, 2000: 905-926). However, the assumption of normality of residuals in the standard Tobit model is not satisfied in our case. Under these conditions, the Maximum Likelihood estimators of the standard Tobit model are not consistent. Alternative specifications of the Tobit model have been formulated that account for departures of the distributions from normality (see Greene, 2000: 916). The variables reflecting the innovative performance of firms are highly skewed, and accordingly, the pattern observed in the empirical distribution is better represented by lognormal distributions. Other studies, facing similar problems in terms of similar characteristics of skewness and departure from normality, have proposed a log-transformation of the Tobit model with a multiplicative exponential error term (Filippucci, Drudi, & Papalia, 1996; Papalia & Di Iorio, 2001). We apply this approach to the study of innovative performance and assume a lognormal distribution for the residuals of the Tobit model. This model introduces a latent variable, INN*, as a logarithmic transformation of an observed measure of innovative performance, INN: that is, INN* = ln (1 + INN). It is then assumed that the latent variable of innovative performance of a firm *i* is a function of a number of explicative variables.

Descriptive statistics are given in Table 3. From the table it can be seen that on average, 2.81 per cent of firms' turnover can be attributed to products new to the world (INNWORLD), while 4.94 per cent of firms' turnover pertain to innovations new to the firm (INNFIRM). 4.94 per cent can be attributed to turnover in significantly improved products (INNIMP). Moreover, on average, firms use about seven sources of knowledge for their innovative activities, but they use only about one source deeply. Simple correlations between our explanatory variables can be found in Appendix Table 1.

[Table 3, just about here]

The results of the Tobit regression analysis can be found in Table 4. We find strong support for the hypothesis that external search breadth is curvilinearly – taking an inverted U-shape – related to innovative performance. First, the parameter for external BREADTH is significant and positive for all degrees of novelty of innovation (INNWORLD, INNFIRM, INNIMP), showing that the breadth of openness of firms' innovative search is an important factor in explaining innovative performance. Second, the parameter for BREADTH squared is significant as well, showing that if firms use too many sources in their search for innovation there are decreasing returns. In the case of innovations new to the world (INNWORLD), the point where search has negative consequences for performance – what could be called the 'tipping point - is at eleven sources, so that if firms use more than eleven sources of external knowledge for their innovative activities, decreasing returns are likely to set in.

[Table 4, just about here]

We also find rather strong support for the hypothesis that external search depth is curvilinearly – taking an inverted U-shape – related to innovative performance, since the variable measuring the DEPTH of openness and the squared term are both significant and have the expected signs for INNWORLD and INNFIRM. However, for INNIMP the parameters are not significant. In the case of INNWORLD, the "tipping point" is three sources only, so that if firms use more than three sources of external knowledge deeply for their innovative activities, decreasing returns are likely to set in.

With respect to our statement that the more radical the innovation, the less effective external search breadth will be on innovative performance, we do find some evidence for the hypothesis. In particular, the parameter for BREADTH in the case of INNWORLD is the smallest; INNFIRM is higher; and the parameter for INNIMP is the highest. In other words, while the parameter for BREADTH is significant and positive for all degrees of novelty of innovation, the parameter is smaller the more radical the level of innovation.

The hypothesis stating that the more radical the innovation, the more effective external search depth will be on innovative performance also finds strong support.

The parameter for DEPTH of openness is the highest in the case of INNWORLD, while INNFIRM is lower and the parameter for INNIMP is the smallest to the extent that it is insignificant.

Our final hypothesis, asserting that drawing deeply from lead users in innovative search increases the probability of the firm to achieve innovative performance, finds support in the case of more radical innovations (INNWORLD) and for product improvements (INNIMP), but not in the case of products new to the firm (INNFIRM).

Of our control variables, the parameters for R&D intensity (RDINT), the scope of the market (GEOMARKET) and co-operation in innovative activities (COOP) are consistently positive and significant in explaining the proportion of sales due to novel products no matter the degree of novelty of the product. The size of the firm only seems to matter for the two incremental types of innovation (INNFIRM and INNIMP) with larger firms having more sales of new products as compared to smaller firms. For radical innovation, the size of the firms appears to have no bearing on the innovative performance of the firm. This finding is consistent with the findings of previous studies of innovative performance (see Laursen & Foss, 2003). Whether or not the firm is a start-up has no positive influence on innovative performance, no matter whether or not this is conditional on the R&D intensity of the firm.

DISCUSSION AND CONCLUSIONS

The analysis shows that openness matters for innovative performance – those firms who are more open also appear to be more innovative. In this respect, Chesbrough and others are right about importance of interaction with external actors for the innovation. Firms can benefit from searching widely and deeply in their innovative activities. External sources can provide ideas and resources that help firms gain and exploit innovative opportunities.

Using a very different dataset and looking across number of industries, we can also confirm Katila and Ahuja's finding that "over-search" may indeed hinder innovation performance. It appears that there are moments or 'tipping points' where openness – in breadth and depth - can negatively affect innovative performance. Why do firms

over-search and why does over-search negatively affect performance? Koput (1997) provides several reasons for the negative effect of over-searching, such as external search may place too many demands on time, diluting attention of the firm. Attention-based theories of the firm would suggest that it is possible to think of the firm as having a pool of attention that can be distributed across different sources and at different rates over time (Ocasio, 1997). This pool can be added to by investments in R&D and therefore creating more absorptive capacity for the integration of external sources (Cohen & Levinthal, 1990). However, at some point and regardless of the level of R&D investment, firms have to make choices between innovative ideas and to decide which ideas should be implemented. In this process, it is possible for search processes become fragmented and ill-structured. Different parts of the organization may have conflicting goals and there may be a few common routines about how best exploit an external idea. There may be limits to the information-processing abilities of the firm, an inability to draw ideas from a wide number of sources. In this environment, search processes can be haphazard and confused, leading to a scattering of effort and dilution of opportunity.

The possibility of "over-search" helps to create a more nuanced view of the role of openness, search and interaction and how they shape innovative performance. The optimistic view of search and openness ascribed great importance to interaction in the development of new innovative opportunities. Our research supports this view, but suggests that this enthusiasm for interaction needs to be tempered by an understanding of the costs of such relationships and of search efforts. Firms do need to search widely and deeply, but they need to careful dilute their attention. Our research suggests that firms need large number of external links and a modest number of deep relationships with key sources of innovative ideas. However these links need to be managed carefully so that search efforts are not dissipated across too many search channels.

Novelty of innovation matters as well. It is possible to learn about the different facets of the innovation process by examining the importance of different factors for performance for different degree of novelty in innovation. Each level of novelty tells a slightly different story about what is important for innovative performance. Much of the literature leaves aside this question and treats all innovation (often partially

measured by the number of patents) as the same. This approach does not allow for the disentangling of the differences between types of innovation.

Future research

The analysis of large scale databases, such as UK innovation survey, poses many questions that can not be investigated without more direct observational research methods. Much greater knowledge is needed about how firms organize their search for external ideas for innovation. Most of the literature on search is based on indirect data and infers relationships from data and existing theoretical models. Yet the empirical base underlying these models is relatively slight and it would be extremely useful to a number of studies of how different organizations organize their search processes. In-depth case studies and observational research, may allow for a more full description of how firms become trapped in the position of over-search.

It would also be useful to more fully examine the relationship between corporate and search strategy. In theory, there should be a relationship between how firms seek to gain and sustain competitive advantage and how they seek to search for ideas for innovation. It might be possible to find explorative and explorative strategies in search corresponding to similar strategies for competitive positioning in the value chain. As yet, there are few empirical studies that explore this link.

Much of the research on search has looked at specific industries, drawing lessons from these industries for management. In this study, we have looked across a number of industries to see whether the patterns that appeared at the industry level could be found in a more general sample. This approach has helped widen the empirical pool of observation, but it would useful to explore differences between firms within each industry. The characteristics of different technological environments may also shape importance of search for performance. Research on search and performance could be part of more general inquiry concerning how differences across industries and technological environments shape the importance of different factors for innovative performance. Our knowledge about how different industry and technological contexts influence the importance of different factors in shaping innovative performance remains scarce.

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Table 1: Sources of information and knowledge for innovation activities in UK manufacturing firms, year 2000 (n=2707).

Type	Knowledge source	Not used	Low	Medium	High
		Percentages			
Market	Suppliers of equipment, materials, components or software	32	20	32	15
	Clients or customers	34	22	28	16
	Competitors	46	27	20	6
	Consultants	62	22	13	3
	Commercial laboratories/ R&D enterprises	73	18	7	2
Institutional	Universities or other higher education institutes	73	17	8	2
	Government research organizations	82	14	3	1
	Other public sector eg. business links, Government Offices	76	17	6	1
	Private research institutes	82	14	4	1
Other	Professional conferences, meetings	58	27	12	2
	Trade associations	52	28	17	3
	Technical/trade press, computer databases	47	27	22	4
	Fairs, exhibitions	42	28	23	7
Specialized	Technical standards	43	23	23	11
	Health and safety standards and regulations	37	24	27	12
	Environmental standards and regulations	39	26	24	11
Average		55	22	17	6

Table 2: Means of external search breadth and depth by industry

	Breadth mean	Depth mean	No. of firms
Food, drink & tobacco	7.23	0.84	212
Textiles	6.12	0.59	157
Wood	6.37	0.75	156
Paper and printing	5.87	0.94	249
Chemicals	9.95	1.23	114
Plastics	6.84	1.09	135
Non-metallic minerals	6.17	0.96	71
Basic metals	7.98	1.07	54
Fabric. metal products	5.70	0.72	293
Machinery	8.59	1.27	210
Electrical	8.86	1.15	444
Transport	7.51	1.18	279
Other	6.52	0.77	333
Average	7.21	0.97	

Table 3: Descriptive statistics

	No. of firms	Mean	Std. Dev.	Minimum	Maximum
INNWORLD	2707	2.81	11.43	0	100
INNFIRM	2687	4.94	13.97	0	100
INNIMP	2687	4.72	12.95	0	100
BREADTH	2707	7.22	5.30	0	16
DEPTH	2707	0.96	1.68	0	16
USER	2707	0.16	0.37	0	1
RDINT	2707	0.60	3.82	0	90.6
LOGEMP	2707	4.14	1.42	0	9.0
STARTUP	2707	0.06	0.24	0	1
GEOMARKET	2707	2.78	0.90	1	4
COOP	2707	0.16	0.37	0	1

Table 4: Tobit regression, explaining innovative performance across UK manufacturing firms

Dependent variables	INNWORLD		INNFIRM		INNIMP	
Independent variables	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
BREADTH	0.549***	0.091	0.617***	0.063	0.795***	0.086
BREADTH2	-0.024***	0.005	-0.027***	0.004	-0.033***	0.005
DEPTH	0.370**	0.167	0.203*	0.112	-0.029	0.136
DEPTH2	-0.057**	0.023	-0.031**	0.015	-0.015	0.018
USER	0.714**	0.332	0.275	0.236	0.912***	0.291
RDINT	0.072***	0.023	0.069***	0.018	0.037***	0.022
LOGEMP	0.026	0.093	0.117*	0.065	0.196**	0.081
STARTUP	-0.022	0.518	0.333	0.349	-1.656***	0.519
STARTUP x RDINT	22.497	14.561	15.419	11.537	0.263	7.659
GEOMARKET	0.739***	0.166	0.546***	0.111	0.621***	0.140
COOP	1.677***	0.287	1.456***	0.202	1.565***	0.248
Industry dummies	Yes		Yes		Yes	
No. of obs	2707		2687		2687	
No. of left censored obs	2307		1986		2123	
No. of right censored obs	16		21		6	
Log likelihood	-1681.2		-2487.3		-2186.2	
Chi-square	324.4***		595.5***		533.5***	
Pseudo R2	0.09		0.11		0.11	

Note: One-tailed *t*-test applied. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

Appendix Table 1: Simple correlations among the independent variables (n=2707).

	DEPTH	USER	RDINT	LOGEMP	STARTUP	GEOMARKET	COOP
BREADTH	0.417	0.294	0.101	0.358	-0.029	0.260	0.303
p-value	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*0.133*	*<.0001*	*<.0001*
DEPTH		0.549	0.099	0.132	-0.012	0.091	0.183
p-value		*<.0001*	*<.0001*	*<.0001*	*0.5495*	*<.0001*	*<.0001*
USER			0.063	0.085	0.031	0.112	0.194
p-value			*0.0011*	*<.0001*	*0.1076*	*<.0001*	*<.0001*
RDINT				0.056	0.007	0.133	0.110
p-value				*0.0035*	*0.7035*	*<.0001*	*<.0001*
LOGEMP					-0.077	0.349	0.215
p-value					*<.0001*	*<.0001*	*<.0001*
STARTUP						-0.018	-0.014
p-value						*0.358*	*0.4742*
GEOMARKET							0.192
p-value							*<.0001*